ANOTHER WAY OF A LIQUID FLOW MEASUREMENTS BY USING A SPECIALLY DESIGNED TURBINE

Matjaž Bunc and Janez Rozman*
School of Medicine, Institute of Pathophysiology, Ljubljana, Slovenia
*ITIS d. o. o. Ljubljana, Centre for Implantable Technology and Sensors, Ljubljana, Slovenia

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Abstract: We designed a special measuring turbine which is suitable for measurements of flow of various liquids in laboratory and animal experimets in medicine. Specifically, the turbine was designed for measurements of blood flow in isolated working pig hearts. The basic principle of measuring of liquid flow through the turbine is based on measurement of the time that elapses when the rotor rotates by one degree. For this purpose, the rotor is equiped with circular and transparent foil having a ring of 360 black lines printed near the circumference of the foil and oriented towards its centre. Sensory part is realized using two infra-red light-emitting diodes mounted on one side of the foil and two photo transistors as sensors of the transmitted infra-red light mounted on the other. By this way, the direction of rotation of the rotor can be identified. The characteristics of electronic part of the turbine are as follows: voltage regulated output ranging from 0 to ± 2.048 V, factor of a transformation described as 1 revolution of a rotor/s = 500 mV at the output (changeable by the programme), calculating time is 2 ms and resolution is 1 mV (11 bits). The electronic part is powered by external power supply of 5V. The turbine showed a linear response at a continuous saline flow up to 3,000 ml min^{-1} at pressure loads of between 20 and 220 cm H_2O. Pressure drop across the turbine depends on the volume flow and was 1 mmHg at 100 ml min^{-1} and 5 mmHg at 7,000 ml min^{-1}. A rotating moment $1.25x10^{-4}$ kg m^2 s^{-1} was calculated. The lowest volume change of a bolus of saline solution, detected by the turbine, was 1.6 ml. Similar, suitable adapted turbine could be used also for measurements of much bigger liquid flows.

Način merenja pretoka tekočin s posebno turbino

Ključne besede: fizika, medicina, pretok tekočin, merjenje pretoka tekočin, turbine merilne, IR svetloba infrardeča

Izvleček: Izdelali smo posebno merilno turbino, ki je primerna za merenje pretoka različnih tekočin pri laboratorijskih in živalskih poskusih v medicini. Pravzaprav smo izdelali turbino za merenje pretoka krvi na izoliranih prašičjih srcih. Osnovni princip merjenja pretoka tekočin skozi turbino sloni na merenju časa, ki preteče ko se rotor turbine zavrti za eno stopinjo. V ta namen je na rotor namesčena okrogla, prozorna folija na kateri je v bližini oboda natisnjenih 360 kratkih, pol stopinje širokih, v središče usmerjenih črnih črtic. Senzorski del je realiziran tako, da sta na eno stran folije nameščeni dve infrardeči svetleči diodi in na drugo stran dva foto transistorja. Tako lahko določimo tudi smer vrtenja turbine. Karakteristike elektronskega dela turbine so: napetostni izhod v območju od 0 do ±2.048 V, faktor pretvorbe 1 obr/s = 500 mV, zgornja meja (programsko določeno) 2.048 V, čas izračuna 2 ms in resolucija 1 mV (11 bitov). Elektronika je preko omrežnega pretvornika napajana z enosmerno napetostjo 5 V. Pri tlakih v območju med 20 in 220 cmH_2O in pretokih fiziološke raztopine do 3000 ml/min je signal na izhodu turbine povsem linearno odvisen od pretoka. Padec tlaka na turbini je odvisen od pretečenega volumna in je pri pretoku 100 ml/min enak 1 mmHg ter pri pretoku 7000 ml/min enak 5 mmHg. Vrtilni moment je bil empirično izračunan in znaša $1.25x10^{-4}$ kg m^2 s^{-1}. Najmanjša sprememba volumna, ki ga zazna turbina je enaka 1.6 ml. Ustrezno predelano turbino je moč uporabiti za merjenje veliko večjih pretokov tekočin.

Introduction

A liquid flow could be measured with flow meters based on different physical principle: an ultrasonic flow meter /1/, laser-doppler flow meter /2/, Venturi flow meter /3/, electromagnetic velocity transducer /4/, pulsed neutron activation /5/, sensing elements based on high-temperature superconductor ceramics /6/ and multiphase turbine flow meter /7/. Some of the above-mentioned flow meters such as the ultrasonic flow meter and laser-Doppler flow meter are not suitable for the measurement of saline liquid flow. One of the possible use of flow meters are also measurements on biologic systems. In experiments on biological systems, when different types of salt solutions are used (such as a heart perfusion), transducers that work on mechanical principles /8/ should be used as one of the proper tools for flow measurements.

The aim of our work was to develop and test a flow transducer based on mechanical principles that could be used as universal equipment for the measurement of continuous liquid flow.

Methods

Description of the mechanical part of the measuring turbine

Both parts of the turbine, the stator, with external dimensions 100 mm x 100 mm x 25 mm, and the rotor are machined from clear plexiglass (Figure 1). The axis and conical bearings are made of pure titanium to prevent the process of corrosion from occurring.

Description of the electronic part of the measuring turbine

The basic principle of measuring the dynamics of liquid flow through the turbine is based on measurement of the time that elapses when the rotor rotates by one degree. For this purpose, the rotor is equipped with transparent foil with a ring of 360 short black lines printed close to its circumference. Two infra-red light-emitting diodes (LED) are mounted on one side of the foil, and two photo transistors as sensors of the transmitted infra-red light are mounted on the other (Figure 2). During rotations of the turbine rotor the printed foil runs

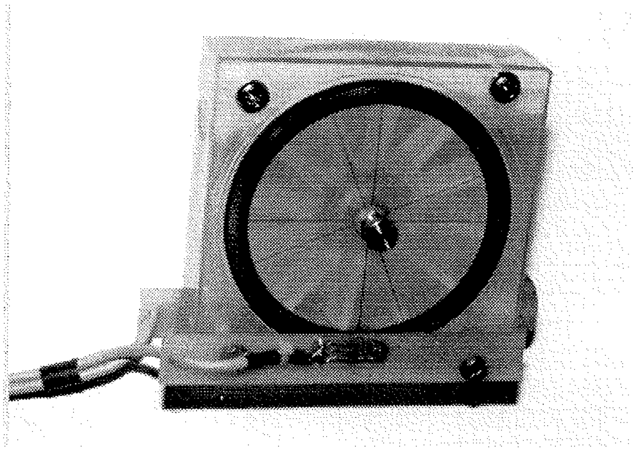

Fig. 1. Picture of the turbine. Both parts of the turbine, the stator with external dimensions of 100 mm x 100 mm x 25 mm, and the rotor, are machined from clear plexiglass.

LEDs and photo transistors and causes interruptions in the transmitted infra-red beam. Since we can expect the liquid to flow also in the opposite direction we used two of each of the afor-mentioned electronic components to enable the micro-controller to define the direction of rotation of the rotor.

Calculation of the turbine rotation moment

The turbine is filled with the saline solution during measurements of saline flow. The rotational moment of the turbine was calculated (estimated) according to a standard physical formula with a few simplifications: a. we proposed that the specific density of both water and plexiglass are of the same value, and b. we assumed that the rotating parts of the turbine and water behave like a rotating cylinder of water.

Calibration of the turbine

Constant pressure of the solution was exerted on the turbine inflow. The time for 3 liters of saline solution (0.9 % NaCl) flow was measured and the speed of the solution flow was calculated /9/. A calibration curve was drawn from the data obtained at certain inflow pressures: 20, 60, 80, 120, 180, 200 and 220 cm H_2O. At the mentioned inflow pressures different flow volumes were reached by using tubes with an inner diameter of 5 mm, 8 mm or 11 mm.

Measurement of pressure drop of the saline solution on the turbine

A pressure drop across the turbine was measured with commercial pressure transducers (Harward Instruments, UK). The transducer for measuring the pressure difference between the turbine inflow and turbine outflow was mounted in parallel to the turbine. One tube connected to one sensor input was mounted inside the inflow part of the turbine and another tube connected to the other inflow of the sensor inside the turbine outflow. Before measurements were taken the transducer was calibrated, so the measured pressure differences could be expressed in mmHg.

Results

Characteristics of the electronic circuitry (Figure 2): Voltage regulated output ranging from 0 to ±2.048 V, 1 revolution per second gives 500 mV at the output (changeable by programming), calculating time 2 ms, resolution 1 mV (11 bits), with an external power supply of 5V.

The turbine showed a completely linear response at a continuous saline flow of 30 – 400 ml min^{-1} at pressure loads between 20 and 220 cm H_2O and tubes with smaller inner diameter of 5 mm. Pressure drop measured across the turbine was 1 mmHg at a saline flow of 400 ml min^{-1}. At a continuous saline flow of 1,000 – 2,000 ml min^{-1}, using tubes of 8 mm inner diameter, pressure drop across the turbine was 1.4 mmHg. With 11 mm inner diameter tubes, higher flow volumes of up to 7,200 ml min^{-1} were produced. A flow dependence of the turbine against the inflow pressures of between 20 to 220 cm H_2O was not linear any more. The pressure drop across the turbine was 2 mmHg at 3,000 ml min^{-1} and 5 mmHg at 7,200 ml min^{-1} (Figure 3). The lowest detected volume flow by the turbine, caused by the bolus of saline solution, was 1.6 ml. That is the volume necessary for the rotation of the turbine by one degree. The calculated rotational moment of the turbine is 1.25×10^{-4} kg m^2 s^{-1}.

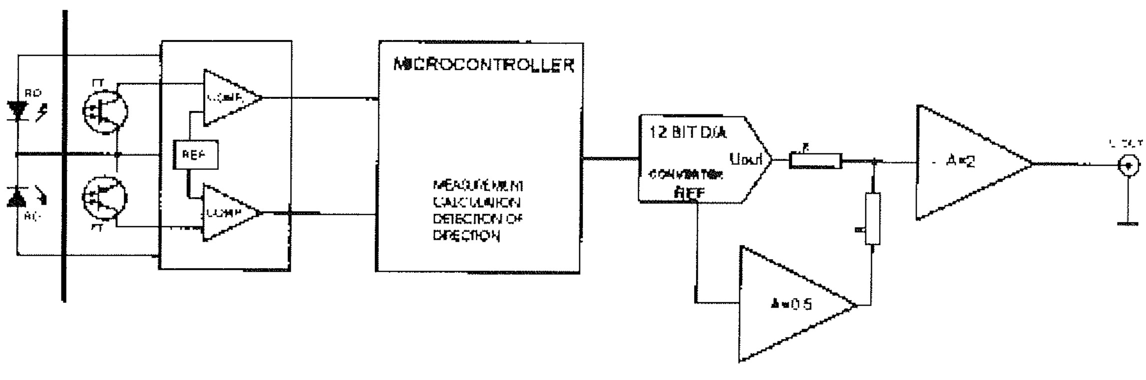

Fig 2. Schematic diagram of the electronic part of the turbine. IRD-infra-red diode, FT-phototransistor, COMP-comparator.

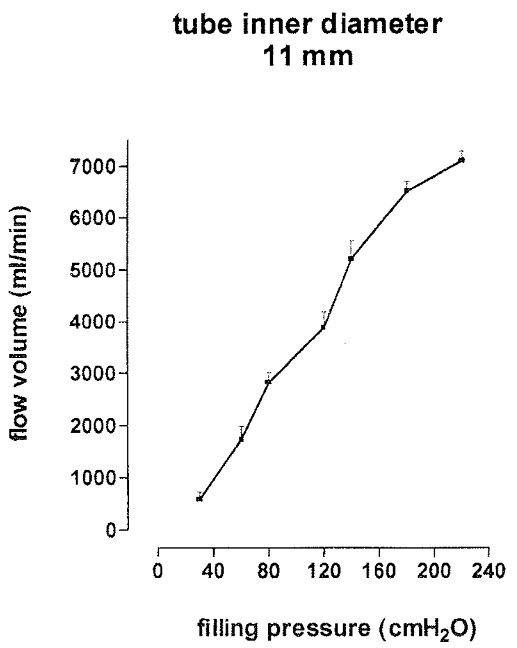

Fig 3. Flow characteristics of the turbine. Constant pressure of the saline solution was created on the turbine inflow. The time for 3 liters of the solution flow was measured and the speed of the solution flow calculated. Each point shows the average of three (n=3) measurements (±SD). A calibration curve was drawn from the data obtained at certain inflow pressures: 20, 60, 80, 120, 180, 200 and 220 cm H_2O. Inner diameter of the tubes was 11 mm.

Discussion

We developed and tested a flow transducer based on mechanical principles that could be used for the measurement of continuous liquid flow. Because of the low rotation moment and high sensitivity, the system is able to measure volume flow changes of only a few milliliters without artifacts. Since the speed of rotation is low, the rotation moment and frequency characteristics of the turbine should have a low influence on the liquid flow through the turbine. The sensitivity of the turbine is quite suitable and is 1.6 ml. There are at least some solutions to improve the sensitivity of the turbine: a. by lowering the volume of the turbine box, b. by making a turbine with more shovels on rotor or, c. by making black lines on the transparent foil even closer together. The turbine is also suitable for the measurements of pulsative fluid flow. According to dimensions and sensitivity, the described turbine is well suited especially for low volume flow measurement. One of the possible use of the turbine are measurements on biologic systems. It is well suited for the experiments on isolated working pig hearts, when different types of salt solutions are used for a heart perfusion. Therefore, transducers that work on mechanical principles /8/ should be used as one of the proper tools for flow measurements. A similar turbine, with adapted dimensions, could be constructed also for making measurements of any volume flow. Our transducer is relatively simple, precise and low in price.

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Matjaž Bunc,
School of Medicine,
Institute of Pathophysiology,
Zaloška 4, 1000 Ljubljana,
Slovenia,
e-mail: Bunc@ibmi.mf.uni-lj.si,
fax: 386 61 443 898.

Janez Rozman,
ITIS d. o. o. Ljubljana,
Centre for Implantable Technology and Sensors,
Lepi pot 11,
1001 Ljubljana, Slovenia
Tel.: 17 01 913
Fax.: 17 01 939
E-mail:janez.rozman@guest.arnes.si

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